1.4 Graphical Description of Uniform Motion

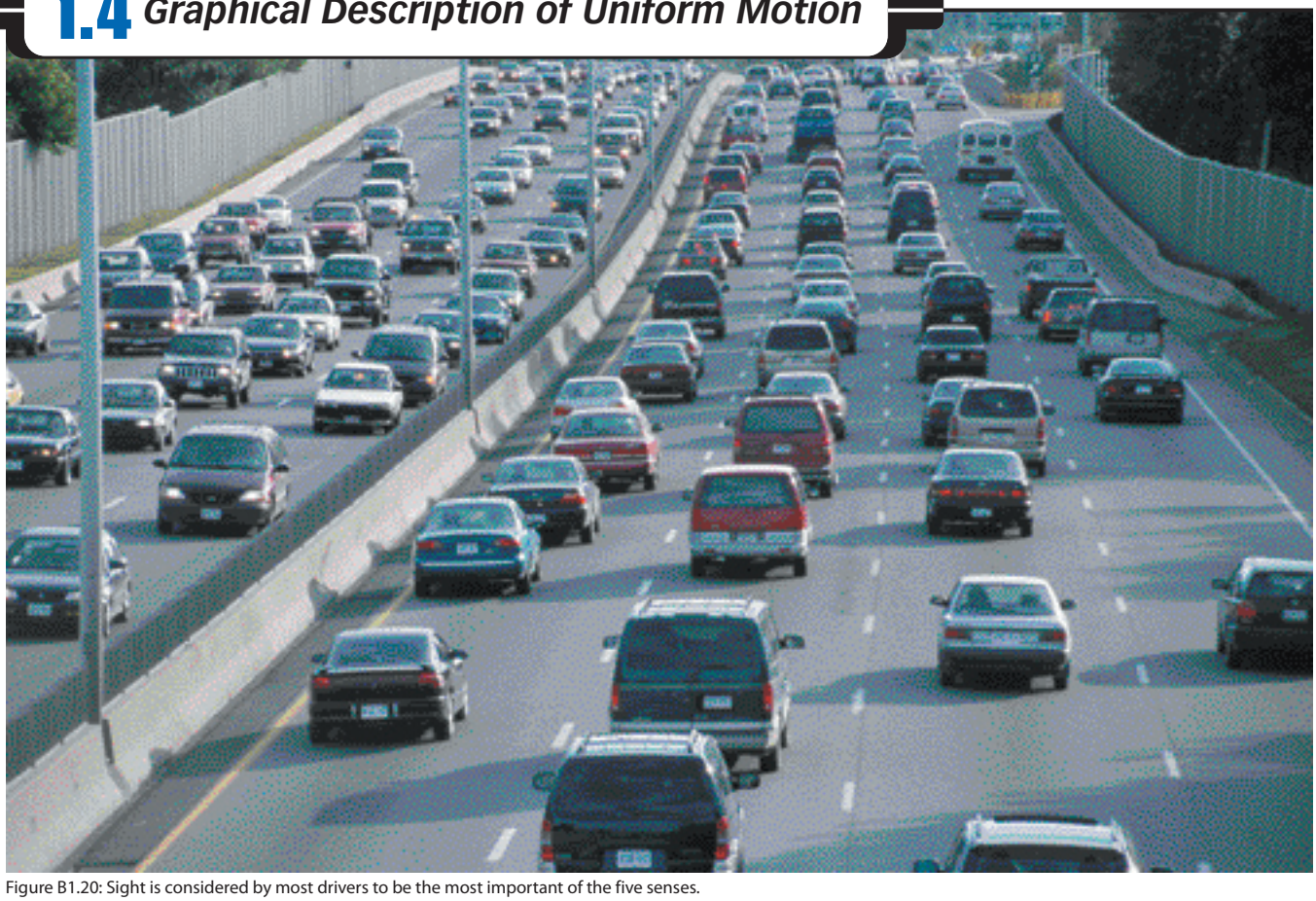


Figure B1.20: Sight is considered by most drivers to be the most important of the five senses.

When you think of your five senses, which one is probably the most essential for driving a vehicle? Most people would likely say sight is most important because it is through the eyes that a driver gathers the most information about the motion of the vehicle and the conditions of the roadway. Unfortunately, if a collision should occur, eye injuries are always a possibility. In fact, automobile collisions are one of the leading causes of eye injuries.

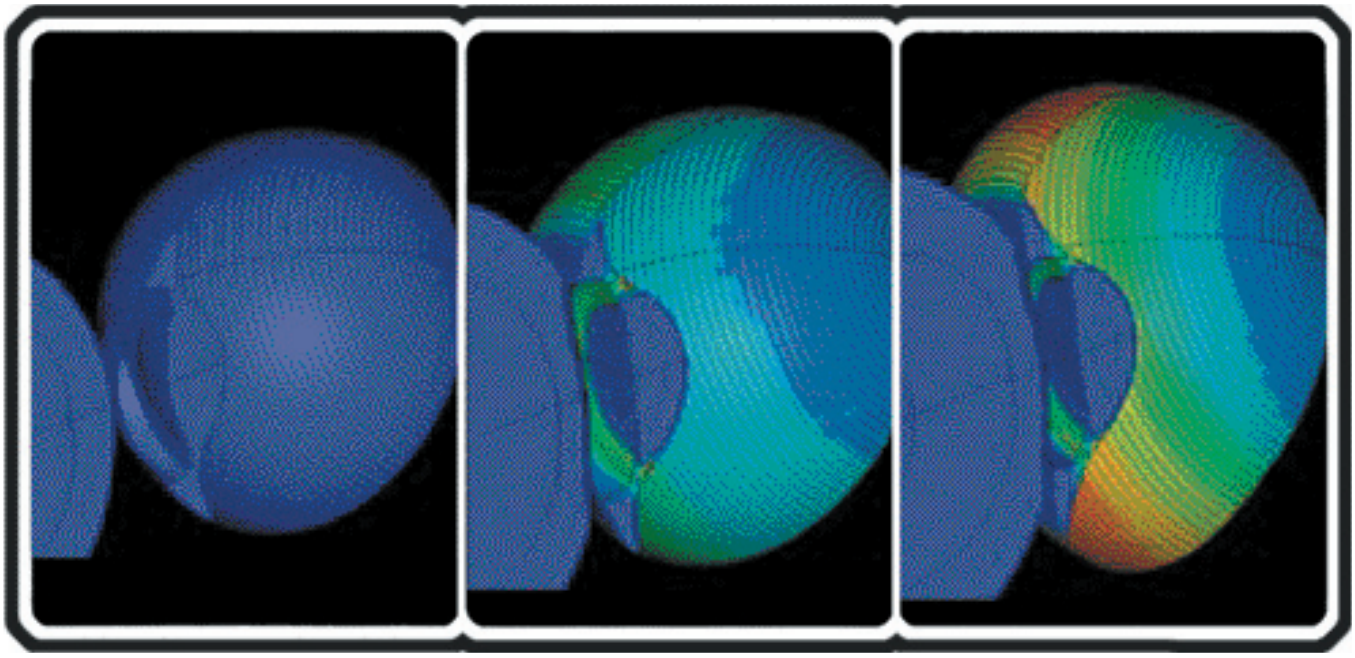


Figure B1.21: Here are computer simulations of an eye hitting the steering wheel at 0.00 milliseconds (left), 0.30 milliseconds (centre), and 0.60 milliseconds (right). The coloured, contour lines represent variations in the stress within the eye.

Practice

19. An accurate computer model of what happens to the human eye provides automobile safety experts with a powerful tool to test new designs for air bags. List the advantages that an accurate computer model of the human eye would provide to automobile safety experts.

Computer Models of Collisions

Motor vehicle collisions are the number one cause of accidental death and injury in Canada. By using computer models to simulate collisions with the eye, as well as with crash test dummies, researchers are learning how to improve the design of air bags and other safety equipment to reduce the occurrence of eye injuries in automobile collisions.

Figure B1.22: Crash test dummies play a vital role in vehicle safety.

If a person's eye is damaged as the result of a collision, it may be necessary for surgeons to perform microsurgery. It is essential that surgeons have precise control of their instruments. In some procedures during eye surgery, the instruments are required to move with uniform motion at only a few tenths of a millimetre per second.

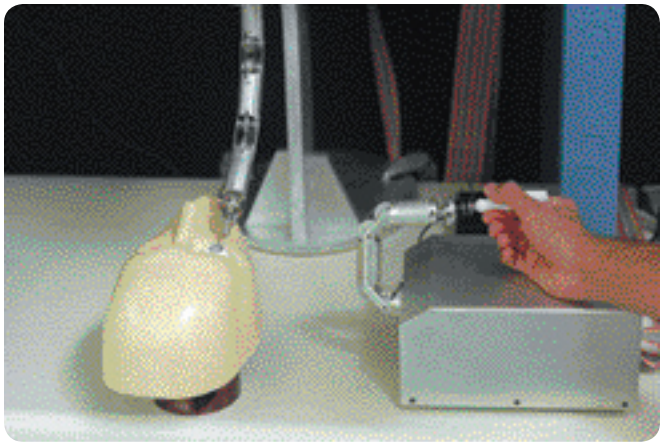


Figure B1.23: Instruments for microsurgery must be tested thoroughly.

Practice

20. Figure B1.23 shows a steady-hand robot arm being tested before the device is used for microsurgery with real patients. A microscope is also part of this apparatus. Why is a microscope essential for the surgeon performing this work?

Graphs Describe the Details of Motion

Given the delicacy of the work, research is now being done using robotics and other computer technologies to control the motion of the instruments used in microsurgery. In this research, graphs are used to give a precise description of the motion of the instruments. Graphs are exceptionally useful because they give very detailed accounts of how the different variables change in relation to each other.

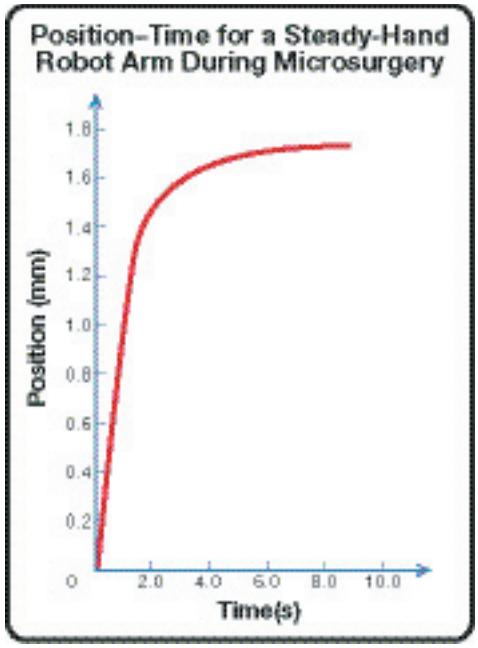


Figure B1.24: The motion of the robot arm during a test can be described using a graph.

Look at Figure B1.24 from the test of the steady-hand robot arm. How was the robot arm moving during the interval from when motion began at $t = 0$ and ending at $t = 1.0$ s? What kind of motion is being described during the interval between $t = 4.0$ s and $t = 6.0$ s? In other words, if a graph tells a story, how does this graph describe the whole motion of the robot arm? To answer these questions, you have to know how to translate back and forth between a written script that describes motion and the corresponding graph. The following activities are designed to help you develop these skills.

The first activity is an investigation in which you will have to know how to set up and label a graph, properly plot data, draw a best-fit line, and find the slope of that line. For a quick review on graphing, turn to pages 537 to 539 and work through "Graphing Skills and Graphical Analysis."

Investigation

Graphical Descriptions of Uniform Motion

Purpose

You will determine the shape of the velocity–time graph for an object moving with uniform motion. By the end of this investigation, you should be able to answer these questions:

- How does the velocity–time graph compare to the shape of the position–time graph?
- How do you determine the average velocity from each graph?
- How do you determine the displacement from each graph?

Prediction

Make predictions for the questions listed in the purpose.

Procedure

Data was collected by using a toy bulldozer as a uniform motion device (UMD). The bulldozer moved at a constant speed in a straight line and pulled tape through a ticker tape timer. The ticker tape timer made 60 dots per second.

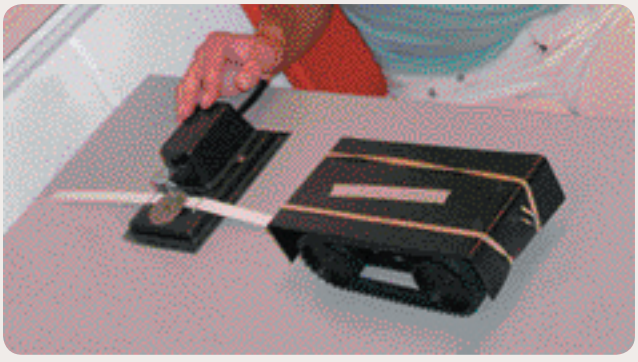


Figure B1.25: A UMD pulls ticker tape through a timer.

Every thirtieth dot was labelled showing the position of the UMD every 0.50 s (as shown in Figure B1.26). Using a metre-stick, the position of the UMD every 0.50 s was measured and recorded in the data table.

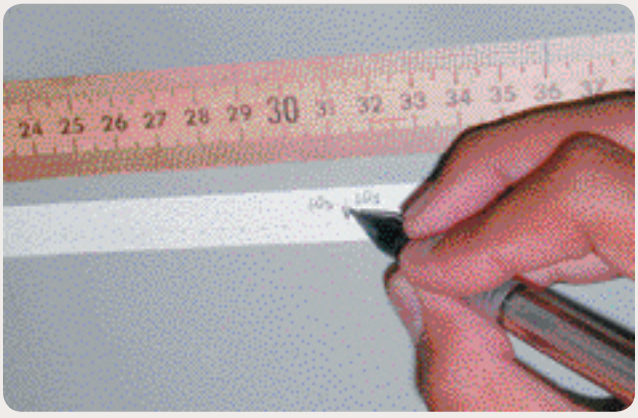


Figure B1.26: Make sure you clearly label the ticker tape.

Science Skills

✓ Analyzing and Interpreting

Data

Copy the following table into your notebook or into a spreadsheet. If you are using a spreadsheet, insert a blank line between each pair of values.

Time (s)	Position (cm)	Average Velocity (cm/s)	Midpoint Time (s)
0	0		
		28.8	0.25
0.50	14.4		
		30.0	0.75
1.00	29.4		
1.50	44.6		
2.00	59.5		
2.50	74.7		
3.00	89.7		
3.50	104.7		
4.00	119.7		
4.50	134.8		

1. Calculate the average velocity for each 0.50-s time interval, and record each value in the appropriate place in the table.

$$\text{average velocity} = \frac{\text{change in position}}{\text{change in time}}$$

$$\vec{v} = \frac{\Delta \vec{d}}{\Delta t}$$

$$= \frac{14.4\ \text{cm} - 0}{0.50\ \text{s} - 0}$$

$$= 28.8\ \text{cm/s}$$

$$\text{average velocity} = \frac{\text{change in position}}{\text{change in time}}$$

$$\vec{v} = \frac{\Delta \vec{d}}{\Delta t}$$

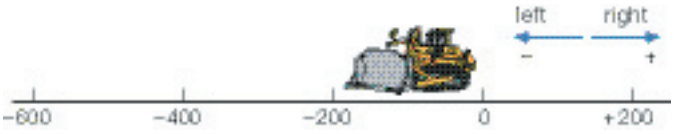
$$= \frac{29.4\ \text{cm} - 14.4\ \text{cm}}{1.00\ \text{s} - 0.50\ \text{s}}$$

$$= 30.0\ \text{cm/s}$$

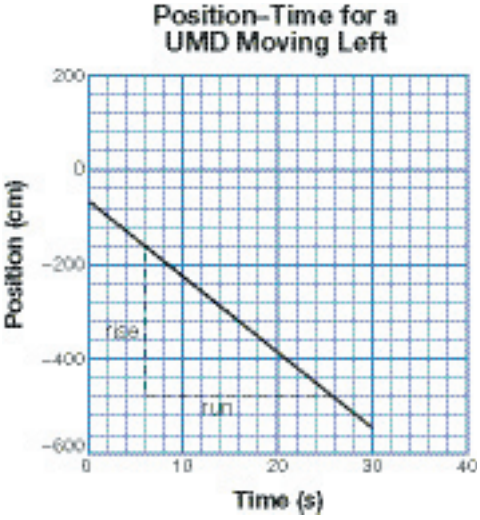
2. Calculate the midpoint time for each time interval, and record it in the table. You will later graph velocity versus time; so, it is reasonable to match the average velocity for an interval with the midpoint time for that interval.
3. Use the first two columns of the table to plot a position–time graph. Remember, since time is the manipulated variable, it goes on the horizontal axis; and position, the responding variable, goes on the vertical axis. Also, draw a best-fit line. If you use a graphing calculator or spreadsheet, the best-fit line can be produced by the process of linear regression.
4. Calculate the slope of the best-fit line on the position–time graph. Be sure to include units.
5. Use the values in the last two columns of the table to plot an average velocity–time graph. Again, draw a best-fit line.
6. Calculate the slope of the best-fit line on the average velocity–time graph. Be sure to include units.

Analysis

7. a. Describe the shape made by the data points plotted on the position–time graph.
   b. How would you determine the average velocity of the UMD using the data shown on this graph?
   c. Is it possible to determine the total displacement for the elapsed time?
8. a. Describe the shape of the average velocity–time graph.
   b. Is it possible to determine the average velocity from this graph?
   c. How would you determine the total displacement for the elapsed time?



Looking at a position–time graph, can you describe how location changes? Even though it is not the variable on either axis, you can determine average velocity by calculating the slope of the position–time graph. Examine Figure B1.27 to see how this is done.



$$\text{average velocity} = \text{slope}$$

$$\bar{v} = \frac{\text{rise}}{\text{run}}$$

$$= \frac{-480\ \text{cm} - (-160\ \text{cm})}{26\ \text{s} - 6\ \text{s}}$$

$$= \frac{-320\ \text{cm}}{20\ \text{s}}$$

$$= -16\ \text{cm/s}$$

Figure B1.27: Average velocity can be determined by calculating the slope of a position-time graph.

Recall that the slope always involves choosing two points on the line and then subtracting values to determine the rise and the run. In Figure B1.27, the UMD was moving to the left. So, according to the sign convention, the position values became increasingly negative, making the velocity negative as well.

You can find out how an object's velocity changes with a velocity–time graph. Since displacement is not the variable on either axis, determining the displacement from this graph requires a calculation.

$$\bar{v} = \frac{\Delta \vec{d}}{\Delta t}$$

$$\Delta \vec{d} = \bar{v} \Delta t$$

$$\text{displacement} = (\text{length})(\text{width})$$

When the equation for average velocity is rearranged, the displacement equals the velocity multiplied by the elapsed time. As shown in Figure B1.28, velocity multiplied by elapsed time corresponds to the length multiplied by the width—the area between the velocity graph and the horizontal $\vec{v} = 0$ line on the velocity–time graph.

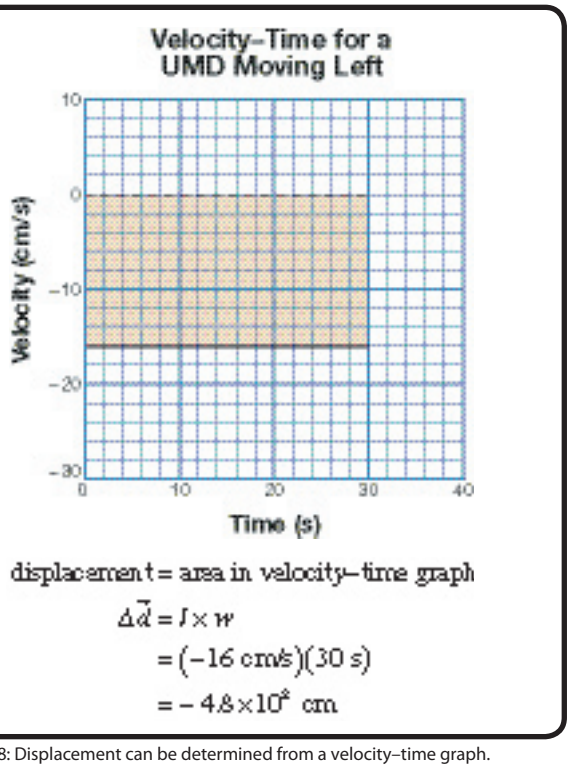


Figure B1.28: Displacement can be determined from a velocity–time graph.

Again, since the UMD was moving left, the negative direction, the velocity value is negative. This, in turn, resulted in the UMD having a displacement that is 480 cm farther left during its 30 s of motion. It is important to realize that the area extends from the line on the graph to the horizontal line where velocity is zero—the area does not extend beyond the $\vec{v} = 0$ line.

Figure B1.29: Robotics is not the only field where computer technology is used to provide precise control over motion. Microprocessors in the controls of mobility scooters help those with limited mobility.

Utilizing Technology

Writing a Script to Describe Motion

Purpose

You will translate verbal descriptions of motion into graphical descriptions using the applet "1D Uniform Motion Builder Graphing (pos, vel)." This applet is located on the Science 20 Textbook CD.

Preparation

Before starting this activity, familiarize yourself with the applet's features by clicking the ShowMe button and working through the instructions that appear. If you need further assistance, click the Help button to answer specific questions. This applet provides a wonderful medium for you to play with the concepts. You will be more comfortable using the software if you spend some time now entering random values and playing with the features.

Procedure and Analysis

1. Previously, you investigated the uniform motion for a device that moved with a velocity of approximately 0.30 m/s over an elapsed time of 4.50 s. Add these values to the appropriate cells to create a motion script for the UMD.
   a. Play the script, and observe the motion. Note that you will have to use the Zoom In feature because the maximum position is less than 2.0 m. Is this uniform motion?
   b. View the position–time graph for the motion on your script. Note that you will have to select time as the variable for the horizontal axis and position (x_0) as the variable for the vertical axis. You will also likely have to use the Zoom features to adjust the scale on the graph, since you only need about 2.0 m on the position axis and less than 5.0 s on the time axis. Does this position–time graph match the one you plotted in the previous investigation?
   c. While still in Graph mode, use the slope tool to determine the slope of the position–time graph. Interpret the meaning of this slope value. Is it consistent with your earlier work?
   d. View the velocity–time graph of the motion on your script. Note that you will have to reset velocity (v_0)—the variable for the y-axis. Again, use the Zoom features to adjust the scale on the graph. Does the velocity–time graph match the one you created in the previous investigation?
   e. While still in Graph mode, use the Area tool to determine the area under the velocity–time graph. Interpret the meaning of this area value. Is it consistent with your earlier work?

Science Skills

✓ Analyzing and Interpreting

Check for Understanding

2. Suppose a rider left base camp and travelled north for 60.0 s at 1.5 m/s. Let north be the positive direction.
   a. Using algebra, determine the displacement of the rider from base camp.
   b. Sketch the position–time and velocity–time graphs for this motion.
   c. Verify the two graphs you sketched by generating them with the applet. Comment on any differences.
   d. Use the velocity–time graph you sketched to determine the displacement of the rider from base camp. Can the applet be used to verify your answer? If so, explain how. Compare this value to your answer to question 2.a. Identify any similarities or differences.
3. Suppose another rider left base camp and travelled south for 30.0 s at 1.8 m/s.
   a. If north is still positive, state the sign—positive or negative—of the velocity and displacement values for this question.
   b. Using algebra, determine the rider's displacement from base camp.
   c. Sketch position–time and velocity–time graphs for this motion.
   d. Verify that the graphs you sketched are correct by comparing the sketches with the same graphs produced by the applet.
   e. Use the velocity–time graph and the interactive capabilities of the applet to determine the displacement of the rider from base camp. Compare this value to your answer to question 3.b.

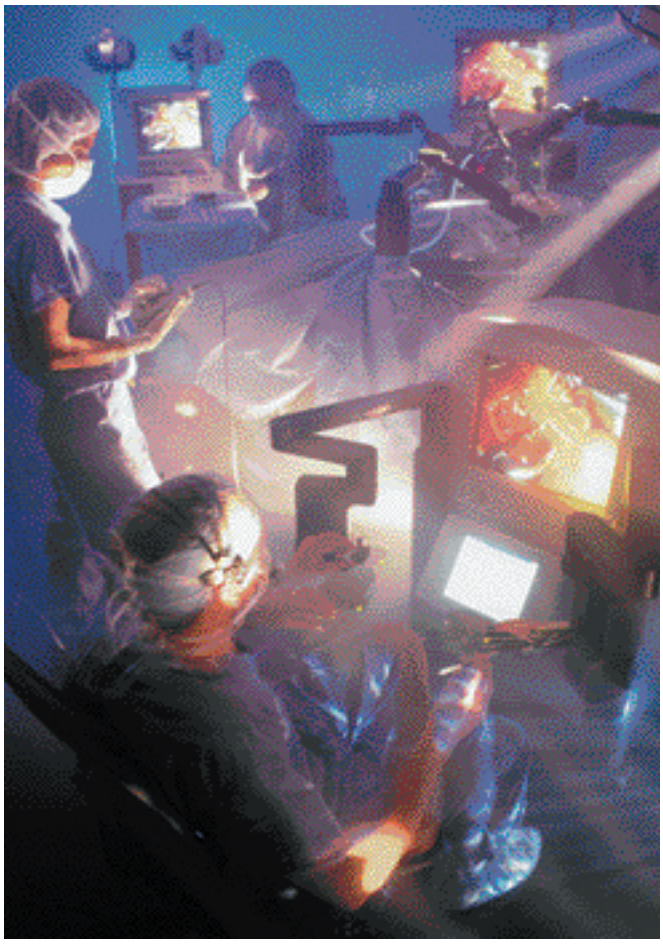


Figure B1.30: Robotic-assisted surgery is now used in many medical procedures in addition to eye surgery.

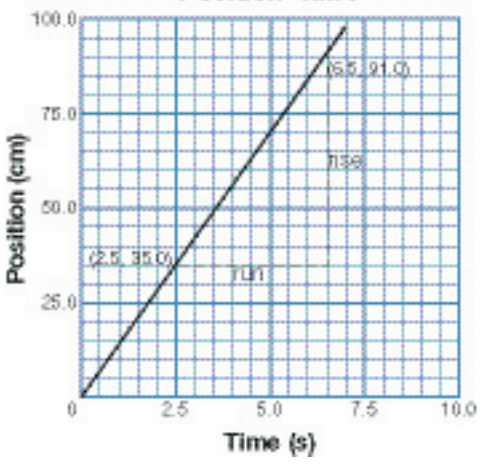
Practice

Use the information presented on page 187 regarding the steady-hand robot arm and Figure B1.24 to answer questions 21 and 22.

21. Carefully examine Figure B1.24 over the time interval t = 0 to t = 1.0 s.
    a. Describe how you would use the graph to determine the average velocity of the robot arm.
    b. Use the method described in question 21.a. to determine the average velocity of the robot arm.
    c. Suppose the experimenters decided to describe the motion of the robot arm during this interval with a velocity–time graph. Sketch the corresponding velocity–time graph for this interval.
22. Carefully examine Figure B1.24 over the time interval t = 2.0 s to t = 6.0 s.
    a. Explain why this part of the graph does not describe uniform motion.
    b. Describe how the robot arm would have to move to produce this portion of the graph.

1.4 Summary

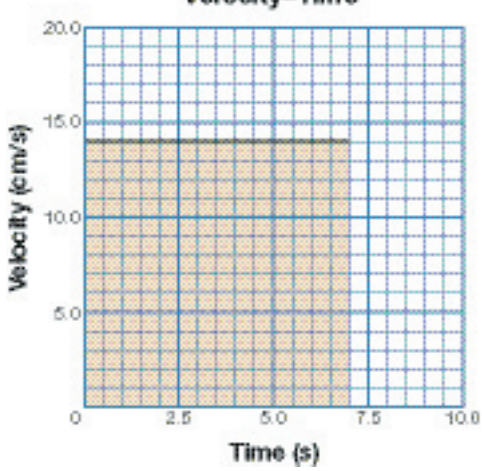
Uniform motion can be described with position–time and velocity–time graphs. For example, a UMD travels across a table at 14.0 cm/s for a total of 7.0 s.



average velocity = slope of position–time graph

$$\vec{v} = \frac{\text{rise}}{\text{run}}$$
$$= \frac{91.0\text{ cm} - 35.0\text{ cm}}{6.5\text{ s} - 2.5\text{ s}}$$
$$= 14\text{ cm/s}$$

This is consistent with the horizontal line on the velocity–time graph.



displacement = area under velocity–time graph

$$\Delta\vec{d} = \text{area of rectangle}$$
$$= l \times w$$
$$= (14.0\text{ cm/s})(7.0\text{ s})$$
$$= 98\text{ cm}$$

This is consistent with the endpoint on the position–time graph.

1.4 Questions

Knowledge

1. Demonstrate your understanding of the following terms by using each in a complete sentence.

- **a.** average velocity
- **b.** displacement
- **c.** conversion factor
- **d.** vector

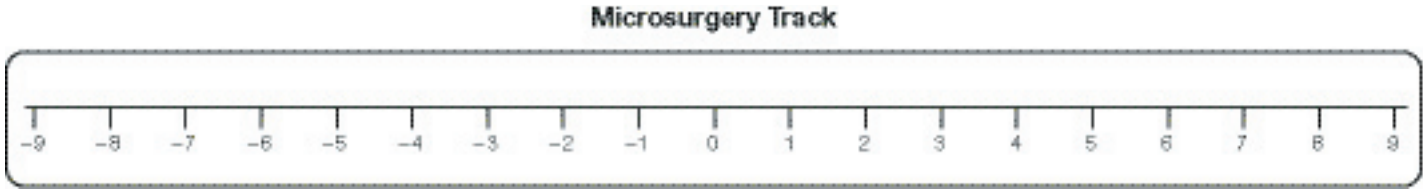
Applying Concepts

2. People without the use of their legs are still able to drive vehicles using hand controls. Hand controls like those shown in Figure B1.31 allow drivers to control the brake and gas pedals with their left hand while steering with their right hand.

- **a.** Identify some desirable features in a hand-control system.
- **b.** People who use hand-control systems travel to and from their vehicles in wheelchairs. Explain why parking spaces for people with disabilities are designed wider than conventional parking spaces and why these spaces are located near entrances.

Figure B1.31: Hand-control systems in vehicles have provided people without the use of their legs the freedom to move about the country/city at their own leisure.

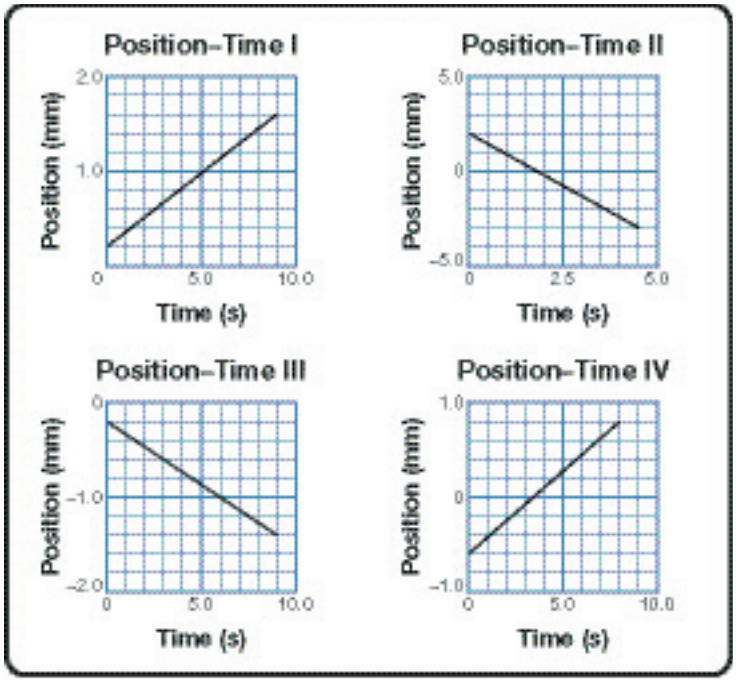
The following diagram shows a scale used to track the motion of a surgical tool during microsurgery. Note how this is set up like a number line—the origin (or reference point) is labelled zero, positions to the right are considered positive, and positions to the left are considered negative.



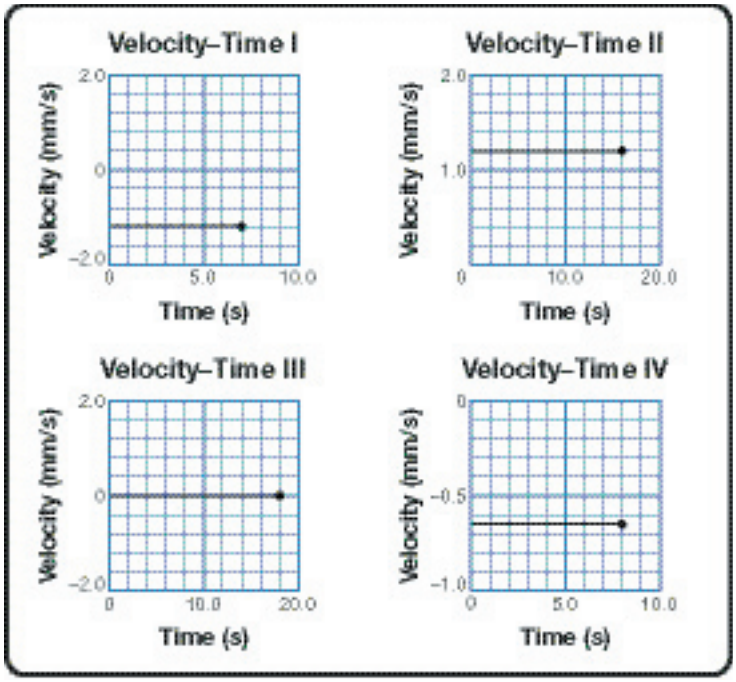
3. The graphs on the right describe the motion of the surgical tool across the microsurgery track in terms of positions and times.

a. For each graph, write a concise description of the motion. Be sure to include the starting position, ending position, and whether the tool was moving left (the negative direction) or right (the positive direction).

b. For each graph, calculate the average velocity of the motion.



4. The graphs on the right describe the motion of the surgical tool across the microsurgery track in terms of velocity and times.

a. For each graph, write a concise description of the motion. Be sure to state how fast the tool was moving and whether the direction was to the right (the positive direction) or to the left (the negative direction).

b. For each graph, calculate the displacement of the tool during this trial.